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Orthoquartzitic Gravels in the Paleogene Muro Group, Southwest Japan

By

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Abstract

The Shimanto Terrain facing to the Pacific Ocean was a geosynclinal area during the Mesozoic to lower Tertiary. The Muro group in the Kii Peninsula, Southwest Japan, occupies the southern part and upper horizon of the geosyncline. In the previous paper (Tokuoka, 1967) the writer reported on the coarser clastic sediments of the Shimanto Terrain in the Kii Peninsula, and discussed its development. He concluded that the provenances of the Shimanto geosyncline were mainly in the northern geanticlinal regions, but that there must have been an old land to the south of the geosyncline, now foundered to ocean depths, from the discovery of exotic gravels. These exotic gravels are orthoquartzites, which have never been found in the present Japanese Islands. He collected and examined 391 samples of orthoquartzitic gravels from the indurated conglomerates in the Muro group at the southern extremity of the Kii Peninsula. In the present paper he will describe their occurrence, size, shape, roundness, rock color and internal sedimentary features. Eighty-six specimens observed under the microscope to clarify their textural and compositional properties will be described. Also considerations will be given to orthoquartzites themselves. Orthoquartzitic gravels in the Muro group have similar characteristics with typical cratonic sandstones such as Sinian quartzites in China or other Precambrian sedimentary quartzites which are distributed worldwide. It may be concluded that there had once been a source area, a part of which must be composed of Precambrian quartzites, to the south of the Shimanto geosyncline, and that it sank below the Pacific Ocean at the close of the geosynclinal development (probably at the end of the lower Miocene).

Introduction

The Shimanto Terrain facing forward the Pacific Ocean is the Mesozoic to early Tertiary geosyncline. In the previous paper (Tokuoka, 1967), the writer reported on its geologic development especially viewed from study of coarser clastic sediments. He concluded that the provenance of the Shimanto geosyncline was mainly in the northern geanticlinal regions which had once been under a geosynclinal condition in the Paleozoic Era. Moreover, his careful examination of conglomerates led to the discovery of exotic gravels; that is, the gravels of sedimentary quartzite or orthoquartzite which had never been found in the present Japanese Islands. Orthoquartzite is one of the most typical cratonic sedimentary rocks and has long been studied by many people. In the previous paper he reported preliminarily on the peculiar characteristics of orthoquartzite gravels and suggested their great importance in clarifying the development of the geosyncline and its basement.

They are well-rounded gravels and most of them are grayish white or light gray in color and some have reddish or purplish tint. Frequently they have a glassy texture similar to chert or metamorphic quartzite. But they are quite different from the latter two rock types by being composed mainly of well-rounded worn quartz grains and secondary overgrown quartz around them with optical and crystallographic continuity. They have supermature composition and excellent sorting and rounding. According to KRYNINE's classification (KRYNINE, 1941) they are first-cycle quartzite, which is generally considered to have been formed after prolonged and intense chemical decay in peneplaned regions. From the fact that there is no occurrence of orthoquartzite in the Paleozoic (Silurian to Permian) or Mesozoic of the present Japanese Islands, and supermature lithologic characteristics of orthoquartzite gravels, the writer considers these gravels to have been derived from the Precambrian rocks in a certain area.

According to the paleocurrent analysis by HARATA (1965), there exist numerous directional structures in the flysch-like beds of the Muro group, many of which show longitudinal E-W trend while some have lateral N-S trend. It is worthy of note that in the southern coastal district many lateral supplies (from south to north) were reported. Furthermore, according to KISHU SHIMANTO RESEARCH GROUP (1968), the orthoquartzite gravels were restricted to the southern subaerial extremity of the Shimanto Terrain, and orthoquartzite-bearing conglomerates were supplied by lateral turbidity currents from south to north. The above-mentioned facts suggest the existence of a land mass (at least a part of which must be composed of Precambrian) now foundered to ocean depths.

The writer will describe precisely the occurrence and petrography of orthoquartzitic gravels which were collected from the southern coastal district of the Kii Peninsula and discuss the above-mentioned problem, as well as the basement of the Shimanto geosyncline. He believes this study will make an appreciable contribution to clarifying the development of the geosyncline and the Pacific Ocean.

The author is grateful to Prof. K. NAKAZAWA for his suggestions and encouragements, and to Dr. T. HARATA and Mr. H. SUZUKI and the other members of the KISHU SHIMANTO RESEARCH GROUP for their valuable discussions and collaborations in the field survey.

Geologic Setting and Occurrence of Orthoquartzitic Gravels

The Shimanto Terrain in the Kii Peninsula is divided into two subbelts, the Hidakagawa belt in the north and the Muro belt in the south. The former is made mainly of the Cretaceous which is called the Hidakagawa group. The latter is composed of the Muro group of the Paleogene to the early Miocene. The Muro

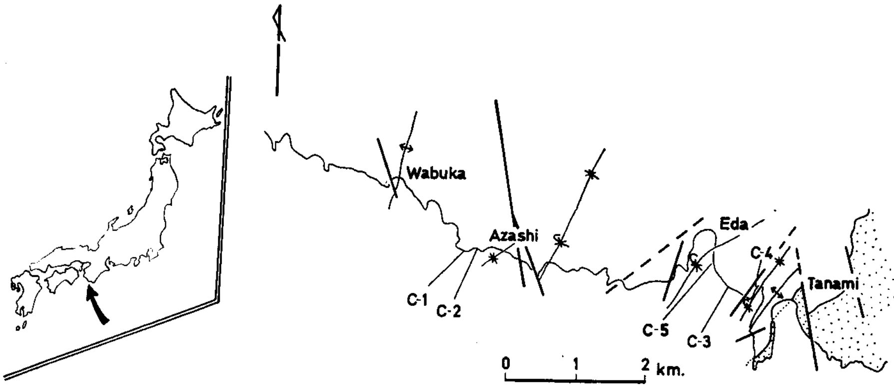

Fig. 1. Index map showing the investigated localities of conglomerates. Heavy lines show the main faults in the Muro group. Dotted area in the right is the Kumano group of the middle Miocene. (TOKUOKA, 1967)

group is divided into the Otonashigawa-muro, Yomurakawa-muro and Ukekawa-muro subgroups in ascending order. It is mainly composed of flysch-like alternations of sandstone and shale frequently intercalating conglomerates. The stratigraphy and geologic structure of the Muro group have become clear in some degree by the efforts of the KISHU SHIMANTO RESEARCH GROUP, but precise data have not been obtained yet owing to the complicated structures and the lack of key beds in monotonous sequences. Orthoquartzitic gravels were found in the Yomurakawa-muro and the Ukekawa-muro subgroups, particularly, in the southern part of the Muro belt. Although regional stratigraphic correlation of the Yomurakawa-muro and the Ukekawa-muro subgroups has not been accomplished, there exists an apparent tendency in the distribution of the orthoquartzitic gravels, that is, the increasing of their size and amount towards the south. At the southern coastal district of the Kii Peninsula shown in Fig. 1, several conglomerate beds were examined and reported by the writer (TOKUOKA, 1967). There the orthoquartzitic gravels attain sometimes to boulder size and occupy about ten to fifteen percent of the total components.

The Muro group of the southern coastal district of the Kii Peninsula was reported by HARATA, TOKUOKA and MATSUMOTO (1963), MIZUNO and IMAI (1964) and KISHU SHIMANTO RESEARCH GROUP (1969). According to KISHU SHIMANTO RESEARCH GROUP (1969), it has a general strike of NE-SW trend and complicatedly folded structures. It can be divided into three formations. The lower and middle formations may be correlated with the Yomurakawa-muro subgroup and the upper formation to the Ukekawa-muro subgroup. The conglomerate beds were examined at five localities shown in Fig. 1. All localities investigated belong to the middle formation. These conglomerate beds are 1–5 m thick, polymictic (Plate 23, Figs. a and b), and intercalated in sandstone-shale sequences. Their textural and compositional properties have already been reported on by the writer (TOKUOKA, 1967). A part of the results is shown in Fig. 2*.

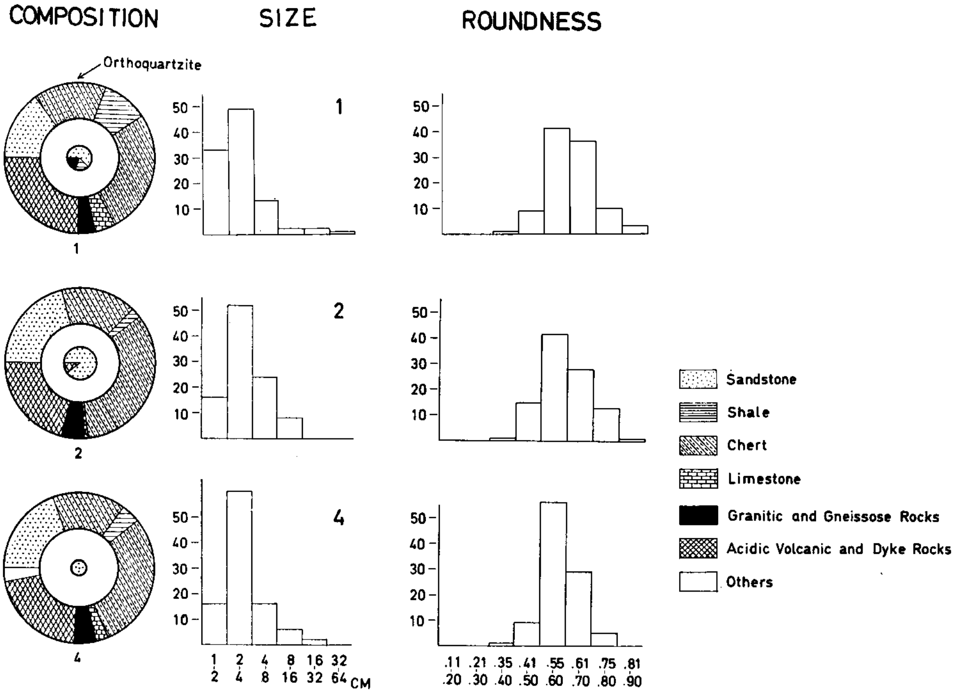

Fig. 2. Properties of the conglomerates of the Muro group. The outer circles at the left show the composition of gravels larger than 1 cm on the exposure surface, and the inner circles show the composition of gravels larger than 10 cm. Rearranged from TOKUOKA (1967).

Properties of Orthoquartzitic Gravels

Megascopic Properties

As many as possible orthoquartzitic gravels were extracted from the indurated conglomerate beds. The specimens obtained amounted to 391, of which 293 specimens were obtained without breaking. First they were classified into two types by unaided eye, that is, granular type (Type I) in which the grains (almost all grains were more or less overgrown secondarily) are visible to the naked eye, and aphanitic type (Type II) in which no grains are visible and whose rock-surface appears glassy. The former type is further divided into two sub-types, Type I-a

* Gravels smaller than one centimeter were disregarded.

having a very small cavity* and Type I-b having no such cavity. Types of orthoquartzitic gravels are shown in Table 1. Textural properties such as size, shape, roundness and color were observed.

1. Size

Size distribution is shown in Table 2 by the length of the longest axis of each gravel. Gravels 2–4 cm in size occupy about 65% of the total, and those 4–8 cm in size about 25%. According to WENTWORTH's size scale, cobbles occupy only 4% of the total and the remainder is all pebble gravels. The biggest specimen** is $15\times13\times9$ cm and the next biggest one is $14\times7\times5$ cm in Loc. C–5. These are shown in Plate 23, Figs. c and d.

2. Shape and surface texture

Shapes of orthoquartzitic gravels are estimated by the ratios of the length of

Table 1. Rock types of orthoquartzitic gravels (Naked eye classification)

Rock type / Loc.	I-a	I-b	II	total
C–1	5	38	81	124
C–2	6	14	17	37
C–3	0	0	1	1
C–4	1	13	36	50
C–5	16	66	97	179
total	28	131	232	391
frequency (%)	7.2	33.5	59.3	100.0

I-a : granular type having a very small cavity
I-b : granular type having no cavity
II : aphanitic type

Table 2. Size distribution of orthoquartzitic gravels

Size in cm. / Loc.	1–2	2–4	4–8	8–16	unclassified broken specimen	total
C–1	5	64	19	0	36	124
C–2	0	14	10	2	11	37
C–3	0	0	1	0	0	1
C–4	13	11	0	0	26	50
C–5	9	101	41	3	25	179
total	27	190	71	5	98	391
frequency (%)	9.2	64.8	24.2	1.8		

* Originally porous samples and specimens porous by weathering were included together in Type I-a. These cannot be distinguished from each other in the present study.

** Recently the most biggest one, whose size is $25.5\times18.2\times16.7$ cm., was discovered by the KISHU SHIMANTO RESEARCH GROUP.

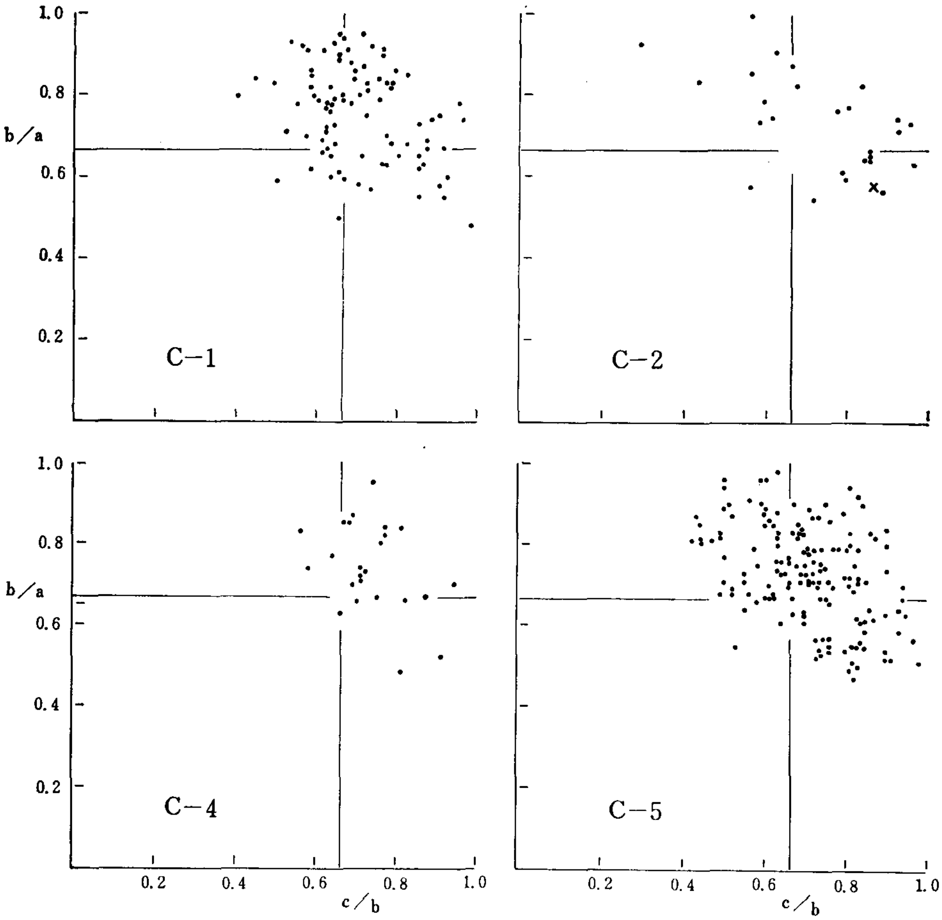

Fig. 3. Zingg's classification of orthoquartzitic gravels in the conglomerates of the Muro group. Crossed mark in the upper right shows the only one gravel from Loc. C–3.

Table 3. Shapes of orthoquartzitic gravels according to Zingg's classification

Shape / Loc.	E	T	B	P	unclassified broken specimen	total	△like
C–1	32	34	8	14	36	124	21
C–2	8	9	1	8	11	37	7
C–3	0	0	0	1	0	1	0
C–4	16	3	1	4	26	50	10
C–5	62	50	4	38	25	179	67
total	118	96	14	65	98	391	105
frequency (%)	40.2	32.8	4.8	22.2			35.8

E: Equant T: Tabular B: Bladed P: Prolate
(△: tetrahedroid)

a, b and c axes, and are shown in Fig. 3 and Table 3 according to ZINGG's classification. The gravels examined have a tendency to converge into the focus of equant (spheroid), tabular (disk), bladed and prolate (roller) shapes. In other word, such gravels may be called tetrahedroid gravels. These gravels, which were classified by the naked eye, attain to 35.8% of the total. Typical tetrahedroid gravels are illustrated in Plate 24, Fig. a~h. Although these are rounded, they have somewhat similar features to the so-called Drei-kanter. There are several pitted gravels which are shown in Plate 24, Fig. n. These features have been referred to as the evidences of wind-worn pebbles by WALTHER (1911), SAITO (1939) and others. But it is hardly possible to think that these may have once been wind-worn gravels and further that they may have been transported again to the geosyncline. Similar tetrahedroid pebbles made simply by mechanical breaking action, were reported by JONES (1953), and there are several samples that are better explained by such origin. The origin of these curious shaped pebbles remains as a future problem. There are several disk-shaped very-rounded pebbles. These were formed undoubtedly under beach condition. Typical disk-shaped ones are shown in Plate 24, Fig. i~m.

3. Roundness

Roundness of gravels is evaluated by KRUMBEIN's charts (KRUMBEIN, 1941) and is shown in Table 4. Excepting a small number of subrounded pebbles, nearly all gravels are rounded or well-rounded. The average roundness is 0.72. High rounding of orthoquartzitic gravels in comparison with the other gravels is one of the most important characteristics, and suggests the different history from that of the other gravels.

4. Color

Color was evaluated by the soil color charts of OYAMA and TAKEHARA (1967), whose estimation is in accordance with the MUNSELL's soil color charts. The determination of rock color of each specimen is not so accurate. It was determined

Table 4. Roundness distribution of orthoquartzitic gravels

Roundness / Loc.	.5	.6	.7	.8	.9	unclassified specimen	total
C-1	1	21	30	38	16	18	124
C-2	0	6	12	15	4	0	37
C-3	0	0	1	0	0	0	1
C-4	3	18	16	11	2	0	50
C-5	5	53	46	48	9	18	179
total	9	98	105	112	31	36	391
frequency (%)	2.5	27.6	29.6	31.6	8.7		

on a slightly wet surface of artificially broken specimen. The orthoquartzitic gravels are classified into the following eight groups and are shown in Table 5.

Group 1. Red-Reddish gray, Purplish gray
Group 2. Dull orange-Bright yellowish brown
Group 3. Light gray-Light yellow
Group 4. Gray-Grayisy yellow, Olive gray
Group 5. White or Grayish white
Group 6. Grayish white
Group 7. Gray
Group 8. Greenish gray, Bluish gray-Dark bluish gray

It is characteristic that there are variable types of rock color. White or grayish white colored specimens (Group 5 and 6) occupy about a half or a little more. Group 1 (Red-Reddish gray, Purplish gray) occupies about 10% and is very important for the reason that such color rocks are typical in the so-called continental red beds.

5. Other miscellaneous properties

The surface of gravels is smooth and somewhat polished in many cases. There

Table 5. Rock color of orthoquartzitic gravels

Color Group / Loc.	1	2	3	4	5	6	7	8	total
C-1	16	1	6	1	33	38	26	3	124
C-2	4	1	2	1	11	12	5	1	37
C-3	0	0	0	0	0	1	0	0	1
C-4	2	0	6	4	9	12	16	1	50
C-5	20	3	9	2	67	43	30	5	179
total	42	5	23	8	120	106	77	10	391
frequency (%)	10.7	1.3	5.9	2.0	30.7	27.1	19.7	2.6	100.0

Group 1. Red-Reddish gray, Purplish gray
7.5R 7/1, 6/1, 6/2, 5/1, 5/2, 5/3, 4/2, 4/3, 4/6, 3/3; 10R 7/1, 6/2, 6/3, 5/3, 5/6; 5YR 4/3; 5RP 7/1
Group 2. Dull orange-Bright yellowish brown
7.5YR 7/3; 10YR 8/3, 7/2, 7/4, 7/6
Group 3. Light gray-Light yellow
2.5Y 7/2, 7/3, 7/4; 5Y 8/2, 7/1, 7/2; 7.5Y 7/1; 10Y 7/1; 2.5GY 7/1
Group 4. Gray-Grayisy yellow, Olive gray
2.5Y 5/2; 5Y 6/1; 7.5Y 6/1; 2.5GY 6/1, 5/1; 5GY 5/1
Group 5. White or Grayish white
N 8/0
Group 6. Grayish white
N 7/0
Group 7. Gray
N 6/0, 5/0, 4/0
Group 8. Greenish gray, Bluish gray-Dark bluish gray
7.5GY 5/1; 10GY 7/1; 10DG 4/1; 5B 6/1, 5/1, 4/1; 5PB 4/1, 3/1

are often pitted gravels and facetted-pebble-like gravels as shown already. There are three specimens having light or dark brown limonite-stained crust approximately 2–10 mm thick, whose feature is shown in Plate 24, Fig. o. Although these properties are limited to the orthoquartzitic gravels, their origin has not been ascertained yet.

6. Internal sedimentary features

The majority of gravels belonging to Type I have massive texture (Plate 25, Figs. a, b and c). In eight specimens change of grain size is observed (Plate 25, Fig. f). In two specimens parallel laminations, 1 to 5 mm thick, are observed (Plate 25, Figs. d and e). There are two other samples having peculiar characteristics; one is an orthoquartzite gravel made of granule-sized well-rounded grains, and the other one is an orthoquartzite gravel whose surface-texture is mylonitic (Plate 25, Figs. g and h).

Sedimentary Petrography of Orthoquartzitic Gravels

1. Classification

The writer observed 86 orthoquartzitic gravels in thin slices. Carozzi (1960) classified the pure quartz sandstone series into several types mainly by textural characteristics observed under the microscope. According to his classification the greater majority of orthoquartzitic gravels here treated belong to quartzite in which the totality of the quartz grains have been submitted to a secondary overgrowth of quartz, and the small remainder to quartzitic pure quartz sandstone in which the secondary overgrowth of quartz affects the majority but not the totality of the quartz grains. On the other hand, Pettijohn (1957a) classified sandstones by their compositional differences. According to his classification, nearly all are assigned tc orthoquartzite, and the rest to feldspathic sandstone (in other words, feldspathic quartzite). The compositional differences among examined specimens are so small that the writer classified the orthoquartzitic (orthoquartzite and feldspathic quartzite) gravels into the following types mainly according to their textural characteristics observed under the microscope.

Classification

A. Quartzite without schistosity

A-1. Secondary overgrowth of quartz is developed but each worn quartz is clearly shown by dust rings (Plate 26, figs. a and b). Unpressolved or slightly pressolved texture is shown by long or tangential grain contacts. Detrital matrix is completely negligible.

A-2. Dust rings are observed but not completely. Sometimes pressolved texture is shown by concavo-convex or sutured grain contacts. Precise amounts of secondary overgrowth or other textural and compositional properties are often difficult to estimate. Detrital matrix sometimes exists, but in small quantity.

A-3. Dust rings are rarely visible, and often highly pressolved. Weakly metamorphosed textures are sometimes observed. Textural and compositional properties are difficult to show numerically. Their sedimentary origin is apparent by worn accessory mineral or feldspar grains and/or existence of recrystallized detrital matrix.

B. Schistose quartzite
   Original grains are deformed and often highly pressolved. Original detrital matrices, if existing, are completely changed to chloritic minerals. However their sedimentary origin is apparent by partly preserved dust rings around quartz grains (Plate 26, figs. c, d and e) or by the existence of worn accessory minerals. Sometimes a sedimentary origin also becomes clear from the feature of secondary recrystallized matrices.

C. Miscellaneous quartzite probably of sedimentary origin
   C-1. Quartzite without schistosity. Their origin is not clear, but they are probably of sedimentary origin judging from some vague textural properties.
   C-2. Schistose quartzite probably of sedimentary origin without ascertained evidences.

Eighty-six orthoquartzitic gravels were classified and are shown in Table 6. Type A occupies about 80% of the total. Type B and C occupy about 10%, respectively. The above results are important for imagining the condition of their original source.

Table 6. Rock types of orthoquartzitic gravels (Microscopical classification)

Rock type / Loc.	A-1	A-2	A-3	B	C-1	C-2	total
C-1	8	8	10	4	2	1	33
C-2	5	6	1	3	1	3	19
C-3	0	0	1	0	0	0	1
C-4	2	1	1	1	0	0	5
C-5	6	15	4	2	1	0	28
total	21	30	17	10	4	4	86
frequency (%)	24.4	34.9	19.7	11.6	4.7	4.7	100.0

2. Mineral composition

The mineral composition of orthoquartzitic gravels consists of six components, that is, detrital quartz, secondary overgrown quartz, chert, feldspar, rock fragments, accessory minerals and matrix. The writer determined these in 54 thin sections, which are summarized in Table 7 together with the other properties. According to PETTIJOHN's classification (PETTIJOHN, 1957a), about 90% of them belong to orthoquartzite, and about 10% to feldspathic quartzite. When the amount of secondary quartz is distinct, the composition of each is recalculated excluding secondary quartz, and the results are shown in Fig. 4.

Detrital quartz

Detrital quartz is the most important constituent. In many specimens it is difficult to distinguish detrital quartz from secondary enlarged quartz precisely. In only 19 specimens the precise amount of detrital quartz could be determined. It attains to about 70% to 90% of the total components. When recalculated excluding secondary quartz, it attains to 90% to 100%.

Table 7. Compositional and Textural Properties of Orthoquartzitic Gravels

Specimen No.	Loc.	Total quartz	Detrital quartz	Secondary quartz	Chert	Feldspar	Rock fragments	Accessory minerals	Matrix	Type of quartz grain a	b	c	d	Roundness of quartz grain Mean	Minimum	Median (mm)	Sorting	Skewness (log Sk)	Rock type	Rock name	Remarks
4	C-1	96.7	—	—	0	0	tr	0.9	2.4	97.5	1.5	tr	1.0	—	—	0.44	1.24	−0.01	A-2	Or. qt.	
10	C-1	99.7	—	—	—	0	tr	tr	0.3	94.5	3.0	0.5	2.0	—	—	0.38	1.22	0.01	A-2	Or. qt.	
11	C-1	97.5	—	—	—	—	0.7	0.3	1.5	96.5	3.5	0	tr	—	—	0.37	1.39	−0.04	A-2	Or. qt.	
14	C-1	98.6	—	—	—	0	—	1.2	*	—	—	—	—	—	—	—	—	—	A-3	Or. qt.	0.2% Miscellaneous.
27	C-1	94.5	71.5	23.0	0	4.7	0	tr	0.8	98.5	1.5	0	0	.71	.6	0.62	1.24	−0.01	A-1	Fel. qt.	Abrupt change of grain size
28	C-1	100.0	—	—	0	0	0	0	0	—	—	—	—	—	—	—	—	—	B-1	Or. qt.	
30	C-1	100.0	82.5	17.5	0	0	0	0	0	98.5	1.5	0	0	.73	.6	0.53	1.18	+0.00	A-1	Or. qt.	
38	C-1	99.7	77.0	22.7	tr	0	0	0	0.3	96.0	2.5	—	1.5	.75	.6	0.33	1.12	−0.02	A-1	Or. qt.	
44	C-1	95.9	—	—	0	0	0	tr	4.1	95.5	4.0	0	0.5	—	—	0.41	1.35	−0.00	A-2	Or. qt.	
45	C-1	100.0	—	—	0	0	0	0	0	—	—	—	—	—	—	—	—	—	B-1	Or. qt.	Partly micropressolved
46	C-1	99.7	75.8	23.9	tr	0	0	tr	0.3	99.5	0.5	tr	0	.76	.6	0.54	1.18	−0.00	A-1	Or. qt.	
47	C-1	99.1	87.1	12.0	—	0	0.3	tr	0.6	100.0	0	0	0	.74	.6	0.49	1.26	0.02	A-1	Or. qt.	
49	C-1	97.0	—	—	—	0	tr	tr	3.0	95.5	1.5	1.0	2.0	—	—	0.57	1.21	−0.02	A-2	Or. qt.	
50	C-1	97.7	—	—	0	0	tr	0.1	1.8	99.0	1.0	0	0	.60	.4	0.29	1.19	0.07	A-1	Or. qt.	0.4% Miscellaneous
54	C-1	100.0	—	—	0	0	0	0	0	—	—	—	—	—	—	—	—	—	A-3	Or. qt.	
55	C-1	99.0	—	—	tr	0	0.5	tr	0.5	96.0	4.0	tr	tr	.69	.5	0.17	1.20	−0.03	A-2	Or. qt.	
58	C-1	99.6	—	—	0	tr	0.1	tr	0.3	99.0	1.0	0	0	—	—	—	—	—	A-3	Or. qt.	Highly interlocking
62	C-1	88.8	—	—	—	7.2	—	tr	4.0	97.0	2.0	0	1.0	—	—	—	—	—	A-3	Fel. qt.	
66	C-1	90.8	—	—	0	—	—	tr	9.2	—	—	—	—	—	—	0.54	1.32	0.03	A-2	Or. qt.	
67	C-2	87.9	—	—	0	9.9	tr	0	2.2	—	—	—	—	—	—	—	—	—	A-2	Fel. qt.	Comparatively ill sorted
69	C-2	100.0	—	—	0	0	0	0	0	—	—	—	—	—	—	—	—	—	B-1	Or. qt.	
70	C-2	98.3	79.1	19.2	0.7	0.8	tr	tr	—	97.0	1.5	1.5	tr	.64	.4	0.34	1.23	±0.00	A-1	Or. qt.	0.2% Miscellaneous
71	C-2	99.2	—	—	0	0	0	tr	0.8	94.0	3.5	2.5	—	—	—	—	—	—	A-2	Or. qt.	
73	C-2	99.4	—	—	0	0	0	tr	0.6	97.0	2.5	0.5	tr	(.7)	(.6)	0.57	1.23	−0.00	A-2	Or. qt.	
74	C-2	97.2	—	—	0	0	—	tr	1.5	95.5	4.0	0	0.5	—	—	0.50	1.20	±0.00	A-3	Or. qt.	1.3% Miscellaneous,**
75	C-2	99.5	—	—	0	tr	tr	tr	0.5	94.0	6.0	tr	—	—	—	—	—	—	A-2	Or. qt.	
78	C-2	99.4	86.8	12.6	tr	0	0.2	0	0.4	97.5	1.5	1.0	tr	.68	.6	0.29	1.39	0.08	A-1	Or. qt.	
102	C-2	99.2	—	—	0	tr	0	tr	0.8	97.0	1.5	0.5	1.0	—	—	0.62	1.21	−0.02	A-2	Or. qt.	
108	C-2	99.4	83.5	15.9	0	0	0	0	0.6	99.5	0.5	0	0	.78	.6	0.40	1.25	−0.02	A-1	Or. qt.	
110	C-2	99.4	79.2	20.2	tr	0	tr	0.1	0.5	99.5	0.5	0	0	.73	.6	0.40	1.19	−0.00	A-1	Or. qt.	
117	C-4	99.3	—	—	—	tr	0.1	tr	0.6	100.0	0	0	0	(.6)	(.4)	0.37	1.32	0.02	A-2	Or. qt.	
157	C-4	99.4	80.7	18.7	—	0	tr	0	0.6	95.5	3.0	1.0	0.5	.68	.5	0.53	1.19	0.01	A-1	Or. qt.	
173	C-5	90.2	—	—	0	5.8	0	0.8	3.2	98.0	1.0	0.5	0.5	—	—	0.71	1.44	−0.01	A-2	Fel. qt.	Granule included, ill sorted
178	C-5	100.0	84.7	15.3	0	0	0	tr	0	98.0	2.0	0	0	.67	.4	0.42	1.17	−0.02	A-1	Or. qt.	
195	C-5	100.0	—	—	0	0	0	0	0	98.5	1.5	0	0	.73	.6	—	—	—	A-2	Or. qt.	Paralled laminated
209	C-5	99.4	78.9	20.5	0	0	0	tr	0.6	100.0	tr	0	0	.64	.5	0.56	1.46	0.06	A-1	Or. qt.	
237	C-5	75.8	—	—	0	20.6	tr	1.5	2.1	99.5	0	0	0.5	—	—	0.47	1.30	+0.00	A-3	Fel. qt.	
244	C-5	97.5	—	—	0.5	0	0.9	tr	1.1	93.5	4.0	1.5	1.0	.67	.5	0.23	1.21	0.07	A-2	Or. qt.	
245	C-5	95.4	—	—	tr?	0	0.6	0.4	3.6	93.0	5.5	1.0	0.5	—	—	—	—	—	A-2	Or. qt.	
248	C-5	99.6	86.3	13.3	0	0	0	0	0.4	97.5	2.0	0	0.5	.73	.6	0.60	1.27	−0.04	A-1	Or. qt.	
249	C-5	98.6	—	—	0	0	tr	tr	1.4	99.5	0.5	0	0	(.7)	(.5)	0.40	1.19	0.02	A-2	Or. qt.	
252	C-5	99.4	—	—	tr	0	tr	0.3	0.3	96.5	2.5	0.5	0.5	—	—	0.67	1.27	−0.03	A-2	Or. qt.	
255	C-5	99.3	—	—	0	0	0	tr	0.7	100.0	tr	0	0	.69	.5	0.59	1.23	0.03	A-2	Or. qt.	
259	C-5	98.1	83.5	14.6	tr?	0	tr	tr	1.9	98.0	2.0	0	0	.67	.5	0.32	1.16	−0.02	A-1	Or. qt.	
288	C-5	93.1	—	—	tr?	0	0.9	0.5	5.5	98.5	1.5	0	—	—	—	—	—	—	A-3	Or. qt.	
305	C-5	90.7	—	—	tr	tr	1.3	0.3	7.7	92.0	5.0	0	3.0	.68	.5	0.57	1.38	−0.07	A-2	Or. qt.	
327	C-5	81.5	—	—	—	16.5	0.4	tr	1.6	99.0	1.0	0	0	—	—	0.52	1.61	−0.05	A-2	Fel. qt.	
348	C-5	99.3	78.8	20.5	—	0	tr	tr	0.7	100.0	tr	0	tr	.75	.6	0.35	1.23	0.04	A-1	Or. qt.	
381	C-1	87.8	—	—	0	9.5	2.7	tr	*	—	—	—	—	—	—	—	—	—	A-3	Fel. qt.	
418	C-1	92.3	—	—	0	7.1	0.6	tr	*	—	—	—	—	—	—	—	—	—	A-3	Fel. qt.	
825′	C-1	93.0	86.9	6.1	1.4	0	0	tr	5.6	97.5	1.0	0	1.5	.68	.5	0.41	1.82	−0.05	A-1	Or. qt.	
852′	C-1	99.3	77.4	21.9	0.2	0	tr	0	0.6	95.0	3.5	1.5	0	.71	.6	0.47	1.17	0.02	A-1	Or. qt.	
904′	C-2	99.7	77.8	21.9	tr	tr	0	tr	0.3	99.0	0.5	0.5	tr	.67	.5	0.69	1.25	0.02	A-1	Or. qt.	
1025	C-4	96.0	77.8	18.2	tr	0	tr	tr	4.0	99.0	0.5	0.5	tr	.64	.5	0.49	1.50	0.11	A-1	Or. qt.	

* Secondary altered and excluded from the total. ** Micrograding

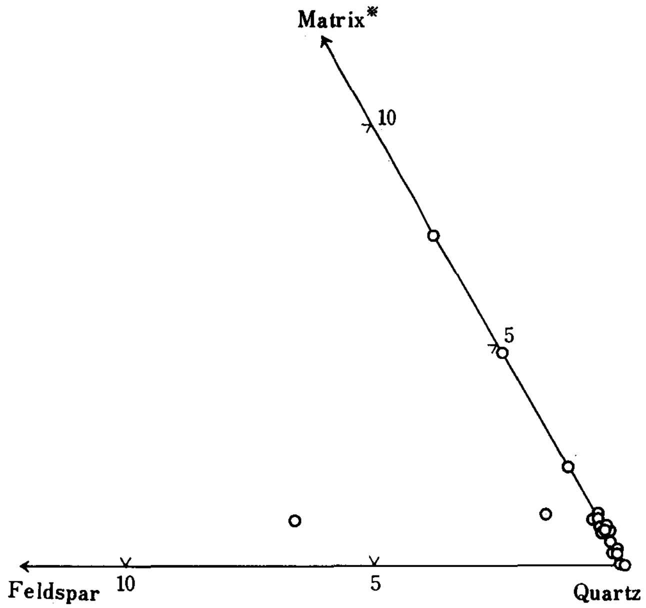

Fig. 4. The mineral composition of orthoquartzitic rocks. Secondary overgrown quartz was excluded from the composition. (*In Matrix, grains of chert or the other rock fragments were included. But their amount is very small in any cases.)

Because of the importance of quartz grains for clarifying the provenance, the writer classified them into four groups. This classification is mainly according to SIEVER and POTTER (1956).

Classification of detrital quartz grains

Type-a. Normal igneous variety or monocrystalline strain-free quartz. (commonly originated in granite)

Type-b. Monocrystalline quartz with undulatory extinction whose angle exceeds 30°. (Probably originated in gneiss or gneissose granite)

Type-c. Polycrystalline quartz or sutured and interpenetrating crystals commonly showing undullose extinction and strain shadows. (Resulted from schist or gneiss)

Type-d. Polycrystalline vein type quartz and quartzitic aggregates. (Resulted from vein quartz or sedimentary quartzite, and sometimes metamorphic quartzite)

In each section, 200 grains whose apparent sizes are between 0.2 and 0.5 mm, were counted. The composition of quartz grains by the above-mentioned classification could be determined in 45 specimens. Sheared specimens, even if very slightly sheared, were excluded from this study. The composition in each specimen is shown in Table 7 and Fig. 5. The mean frequency values in 45 sections are as follows: Type-a 97.4%, Type-b 1.9%, Type-c 0.3%, Type-d 0.4%. Type-a

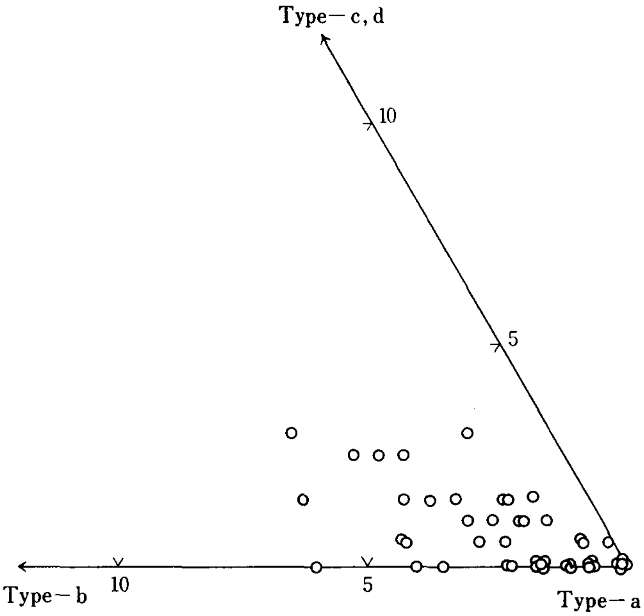

Fig. 5. Types of detrital quartz grains and their composition in the orthoquartzitic rocks.

quartz is very abundant and the other types are very rare or sometimes absent. Type-d grains are of two origins, vein quartz and sedimentary quartzite, and the amount of those of the former origin is larger than that of the latter. Although the grains of sedimentary quartzites are very rare and usually it is difficult to ascertain them under the microscope, their existence is very important.

It is apparent that the original source land of these orthoquartzitic rocks was mostly composed of granites. Gneissose granite or gneiss is very rare. Schist and older sedimentary quartzite are very scarce. There remains the question as to whether detrital grains were derived directly from igneous sources or were supplied from the older sedimentary rocks. This will be considered in the following chapter. Pitted structures are often observed around worn grains, which are often filled by muddy materials.

Secondary quartz

It is usually somewhat difficult to distinguish secondary overgrown quartz from original worn quartz grains. It could be done in nineteen samples. The amount of secondary quartz stretches between 6.1 and 23.9% of the total components. The mean value is 17.8%.

Chert

Chert is very rarely contained in one-third of the examined samples. In the rest no chert grains are visible. It is sometimes difficult to distinguish the chert from fine-grained acidic rocks.

Feldspar

Feldspar is contained in about one-third of the specimens. In exceptional cases it attains to ten or twenty percent of the total components, but mostly to less than ten percent. Potash feldspar or microcline is common, and plagioclase is contained in smaller amount. In 3 samples feldspar grains with authigenic feldspars around them are observed.

Rock fragments

Rock fragments are very rarely discovered in thin sections. They are acidic volcanic rocks, shale, siltstone, siliceous rocks and several undetermined rocks.

Accessory minerals

Accessory minerals are commonly contained (in about four-fifths of samples), but their amount is usually less than 1%. Nearly all of the accessory minerals are tourmaline. Zircons are minor components. Well-rounded tourmaline grain is shown in Plate 26, Fig. g.

Matrix

The amount of detrital matrix is very small, in which the materials forming dust rings are included. Usually its amount is less than 1%. Chlorite, sericite or muscovite altered from detrital matrix often exists. HEALD and ANDERGG (1960) indicated that considerable primary clay may have been replaced by secondary quartz. CAROZZI (1960) also reported that the secondary quartz may have been partly introduced from decomposition or alteration of unstable and clay minerals since deposition. But here these possibilities are disregarded.

3. Textural properties

Grain-size distribution

According to GREENMAN's method (GREENMAN, 1951) grain size distribution of 39 samples was determined under the microscope, and median diameter, sorting coefficient and skewness are collectively shown in Table 7.* Median diameter, sorting coefficient and their mutual relation are shown in Fig. 6. When the specimens are under the effect of pressure solution, the grain size may be considerably modified as indicated by HEALD (1955). Dissolution of finer quartz grains as a possible source of secondary silica was reported by PYE (1944) and GOLDSTEIN (1948). These effects are neglected in this report. All investigated samples show typical unimodal size distribution and are excellently sorted as dune sand or dune-derived beach sand.

* FRIEDMANN (1958) pointed out that GREEMNAN's method is inappropriate when the thin-section data is compared with sieving data, especially in well-sorted sandstones. The writer cannot compare his data actually with recent quartz sands or ancient orthoquartzitic sandstones. It remains as one of the future problems.

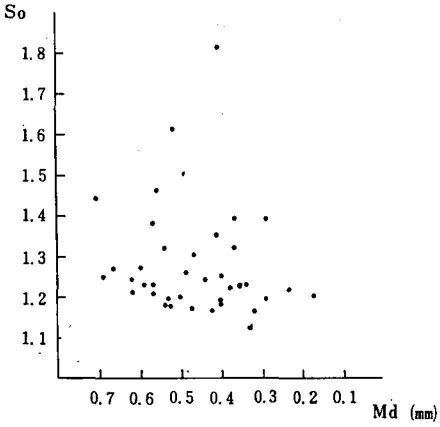

Fig. 6. Sorting coefficients and median diameters of the orthoquartzitic rocks.

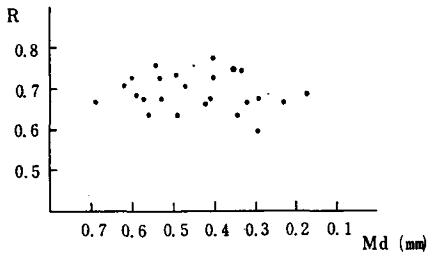

Fig. 7. Roundness values of quartz grains and median diameters of the orthoquartzitic rocks.

Grain roundness

According to KRUMBEIN's charts (KRUMBEIN, 1941), the roundness of 50 quartz grains in each section, whose apparent size was between 0.2 and 0.5 mm under the microscope, was determined. Because of poor preservation of original worn grain surfaces, which can be seen as dust rings, grain roundness could be estimated in only 25 samples. The mean roundness in each section is collectively shown in Table 7. Sutured or irregular contacts due to pressure solution have actually modified original grain roundness in some degree. Such effects were evaluated and excluded as far as possible. In each section the average roundness is about 0.6 or 0.7 and the minimum roundness is 0.5 or 0.6, and sometimes 0.4. Roundness of grains generally depends on their sizes. However, it is impossible to determine their true sizes under the microscope. As shown in Fig. 7 nearly all grains are well-rounded, and there is no intimate relation or coordination between median diameter and mean roundness. It is very interesting that even fine grains have obtained high roundness without exception. It is apparent that all examined specimens are composed of well-rounded or rounded quartz grains like eolian sands.

Several Considerations on Orthoquartzitic Rocks

In the present Japanese Islands there have been known no pure quartzitic sandstones as described in the preceding chapter, so these rocks are not familiar to Japanese geologists. The writer will consider several problems concerning orthoquartzitic rocks.

First-cycle or second-cycle problem

KRYNINE (1941) divided sedimentary quartzites into two groups, first- and second-cycle quartzites. According to him, first-cycle quartzites are pure quartz-sandstones which are formed under the influence of intense chemical decay in peneplaned regions, and second-cycle quartzites are formed through reworking of pre-existing quartzose sediments*. The latter type quartzites are distinguished from the former by the existence of fragments of older quartzites and by the existence of many detrital cherts. PETTIJOHN (1957a) described the existence of two generations of secondary quartz around worn grains in second-cycle quartzite. POTTER and PRYOR (1961) reported from the study of the Paleozoic, Cretaceous, and Tertiary cratonic clastics of the upper Mississippi Valley and adjacent areas that supermature sandstones of Ordovician and Devonian are of second cycle and most of their constituent materials were derived from relatively mature pre-existing sediments. THIEL (1935) reported that exceedingly well-rounded and well sorted St. Peter sandstones of Ordovician age are of second cycle origin. However, in respect to this point, FOLK (1960) had a different viewpoint based on the study of the White Tuscarora and Keefer sandstones of Silurian age in West Virginia, and he pointed that high rounding could be accomplished in one cycle of deposition in the beach and dune environments.

Although it is very difficult to imagine the original source of the orthoquartzitic gravels of the Muro group, several points will be mentioned below. It is apparent petrographically that there exist grains of chert, sedimentary quartzite and other rock fragments, and two generations of secondary quartz indicated by double dust rings as shown in Plate 26, Fig. f. However, it is another problem whether these evidences suggest a second cycle or not. The quantity of rock-fragments is very small, and in many cases there are no such grains. Two generations of secondary quartz is also exceptional. Quartz grains of Type-d, in which sedimentary quartzite and vein quartz are included, are very scarce and often lacking. The writer is inclined to consider that orthoquartzitic rocks were mostly derived directly from the granitic source with very small quantity of accompanying sedimentary rocks. Their supermature properties of excellent sorting and rounding were accomplished under the dune or dune-derived beach condition.

Secondary overgrowth around worn grains

Secondary overgrowth was indicated for the first time by SORBY (1880), and then by IRVING (1883) and IRVING and VAN HISE (1884). From that time many papers on this problem have been published, especially, for the study of diagenesis in sedimentary rocks.

* KRYNINE added the third type quartzites (cleaned graywackes), which are the product of the washing out of the clay and silt portions of graywackes. But in the present case, there are no quartzites of this type.

Secondary overgrowths of quartz around worn quartz grains are visible in abundant specimens of the Muro group. The typical and well-preserved specimen is shown in Plate 26, Figs. a and b. As well known there exists crystallographic continuity between worn grain and secondary overgrown part, and when detrital quartz grain displays undulose extinction, the same inclination is also preserved in the overgrown quartz. When there is a quartz grain consisting of two or more crystal aggregates, the secondary quartz is extincting together with that part of the grain to which it is attached as reported by GILES (1932). In quartzitic pure quartz sandstones and in some quartzites, CAROZZI (1960) distinguished original silica cement from secondary overgrown quartz. But in all specimens here treated, the quartz grains had been entirely submitted to secondary overgrowth of quartz, and even if original silica cement exists, it can hardly be identified.

Authigenic feldspar around abraided feldspar grains was reported by many authors, such as IRVING and VAN HISE (1884), TESTER and ATWATER (1943), GOLDICH (1934), THIEL (1935) and PETTIJOHN (1957a). Recently it was reported by VISWANATHIAN and SINDHIA (1969) with respect to Precambrian arkosic sandstones in India. CROWLEY (1939) stated that authigenic feldspars may have grown under marine condition. Only three examples could be obtained in the specimens examined. In Plate 26, Fig. h well-rounded K-feldspar is observed to have overgrown to an anhedral crystal.

Origin of secondary enlarged quartz

This has been one of the interesting problems. PETTIJOHN (1957 a) reported on the following three possibilities. The cementing silica is attributed to introduction and precipitation by ground waters, to solution and reprecipitation of the detrital quartz, and to penecontemporaneous precipitation of silica from sea water. Although the microscopic observation of orthoquartzitic gravels themselves does not suggest the origin of secondary quartz, the writer will venture to point out the following points. Specimens retaining complete original shapes of rounded grains without strain effect and having plentiful overgrowth might be considered to be the last case. KRYNINE also said that more than 90% of secondary silica was really of primary, penecontemporaneous sedimentary origin. But in this respect we must consider the possibility that pressure solution in a certain part may produce plentiful secondary silica and add large overgrowth to another part without any modification of original texture. Such cases were reported by HEALD (1955, 1956) and THOMSON (1957). In many orthoquartzitic gravels from the Muro group, pressolved texture is commonly observed as represented by a pressolved zone or modification of original grains. Microstylorites are sometimes observed. From the above-mentioned it is probable that secondary enlarged quartz may be produced by dissolving silica due to pressure solution.

Conclusive Remarks – Probable Origin of Orthoquartzitic Gravels and Its Meaning to the Development of the Shimanto Geosyncline –

The writer described the occurrences of the orthoquartzitic gravels in the conglomerates of the Paleogene-lower Miocene Muro group at the southern extremity of the Kii Peninsula and several of their petrographic characteristics were mentioned. The properties of conglomerates were investigated at five localities. The orthoquartzitic gravels occupy about 10 to 15% of the total composition in each locality (Fig. 2). Three hundred and ninety-one samples of orthoquartzitic gravels were collected and classified by unaided eye (Table 1). They are mostly well-rounded pebbles (Table 2 and 4). Their shapes and colors were also examined (Table 3 and 5). They are highly indurated and white or grayish white in color, sometimes with reddish or purplish tint. Eighty-six specimens were observed under the microscope and classified into five types by their textural properties under the microscope (Table 6). The mineral compositions were determined in 54 specimens and are collectively shown in Table 7. Many of them are classified as orthoquartzite, and some of them as feldspathic quartzite. Textural properties of orthoquartzitic rocks themselves were examined. The grain-size distribution were determined in 39 samples, and grain roundness also in 25 samples. Their results are shown collectively in Table 7. All specimens show excellent sorting and high rounding of grains without exception.

In conclusion it may be safely said that all orthoquartzitic gravels here treated are in supermature condition. According to FOLK's stages of textural maturity in sedimentary rocks (FOLK, 1951), all gravels are in the fourth stage. The quartzitic rocks from which the above-mentioned gravels were derived must have been originally formed under dune or dune-derived beach environment in a certain continental platform.

The question then arises as to the provenance of the orthoquartzitic gravels. In the present Japanese Islands there have been discovered no such matured orthoquartzitic rocks. Accordingly the source of the orthoquartzitic gravels must be sought in some other area. As the whole Japanese Islands had widely been in geosynclinal condition from the Silurian, it is sure that the source of these gravels were, at least, pre-Silurian. Matured pure quartzitic sandstones are distributed widely in the cratonic regions of the world, for instance, the Huronian sandstone, Jotonian sandstone or Sinian quartzite of the Precambrian, and St. Peter sandstone or Tuscarora sandstone of the Ordovician and so on.

Although there is no positive evidence, the writer considers that the orthoquartzitic gravels may have been derived from certain Precambrian sedimentary quartzites for the following reasons. As mentioned above, the source of the orthoquartzitic gravels must be pre-Silurian, as evidenced by the Sinian quartzites of Precambrian which are distributed widely in the Chinese Platform adjacent to the Japanese Islands. The orthoquartzitic gravels are very similar in their appearances to the Sinian quartzites. Furthermore, the lithologic characteristics (supermatured composition, excellent sorting and rounding of grains, intense development of secondary quartz overgrowth around worn grains and very scare occurrences of chert or the other rock-fragments in the composition) of the orthoquartzitic gravels themselves also suggest a Precambrian origin.

The writer (TOKUOKA, 1967) reported about the conglomerates of the Shimanto supergroup, and concluded that the main provenances were in the northern regions beyond the geosynclinal trough. The acidic igneous rocks in the Inner zone, Paleozoic rocks in the Chichibu Terrain, Ryoke granitic rocks and Jurassic Torinosu group and its correlatives were the main sources. However at the southern extremity of the geosyncline it is somewhat different. The orthoquartzitic gravels are considered to have been supplied from the south by turbidity currents. The amount of gravels increases to the south. These points have already been remarked by HARATA (1964), TOKUOKA (1967) and KISHU SHIMANTO RESEARCH GROUP (1968, 1969). It can be concluded with certainty that there had once been a source area to the south of the Shimanto geosyncline. This source area must be composed, at least partly, of Precambrian sedimentary quartzites. This area had sunk beneath the ocean depths at the close of the Shimanto geosyncline (probably at the end of the lower Miocene). The subsidence occurred in accordance with the beginning of the so-called Green-Tuff Movements in the Island Arc Stage of the Japanese Islands (MINATO *et al.*, 1965).

The discovery of orthoquartzitic gravels throws some light on the nature of the basement of the Japanese geosynclines. As for the basement of the Paleozoic geosyncline, ICHIKAWA *et al.* (1956) referred it to the crystalline basement which belongs to the pre-Silurian metamorphic rocks squeezed out along the Kurosegawa tectonic line in Shikoku and Kyushu as Precambrian rocks. MINATO *et al.* (1965) presumed that there might have existed a land (continent) in the Philippine Sea off Southwest Japan at the time of early Devonian to early Visean. They said that this land could be induced from many geologic indications observable in the Siluro-Devonian deposits in Japan. As to this problem the writer can point out from the discovery of orthoquartzitic gravels and their precise study that the basement of the Japanese Islands must be Precambrian sedimentary quartzites. Of course there must also exist widely distributed crystalline rocks and small accompanying sedimentary or volcanic rocks below the quartzites, from which quartzites were made.

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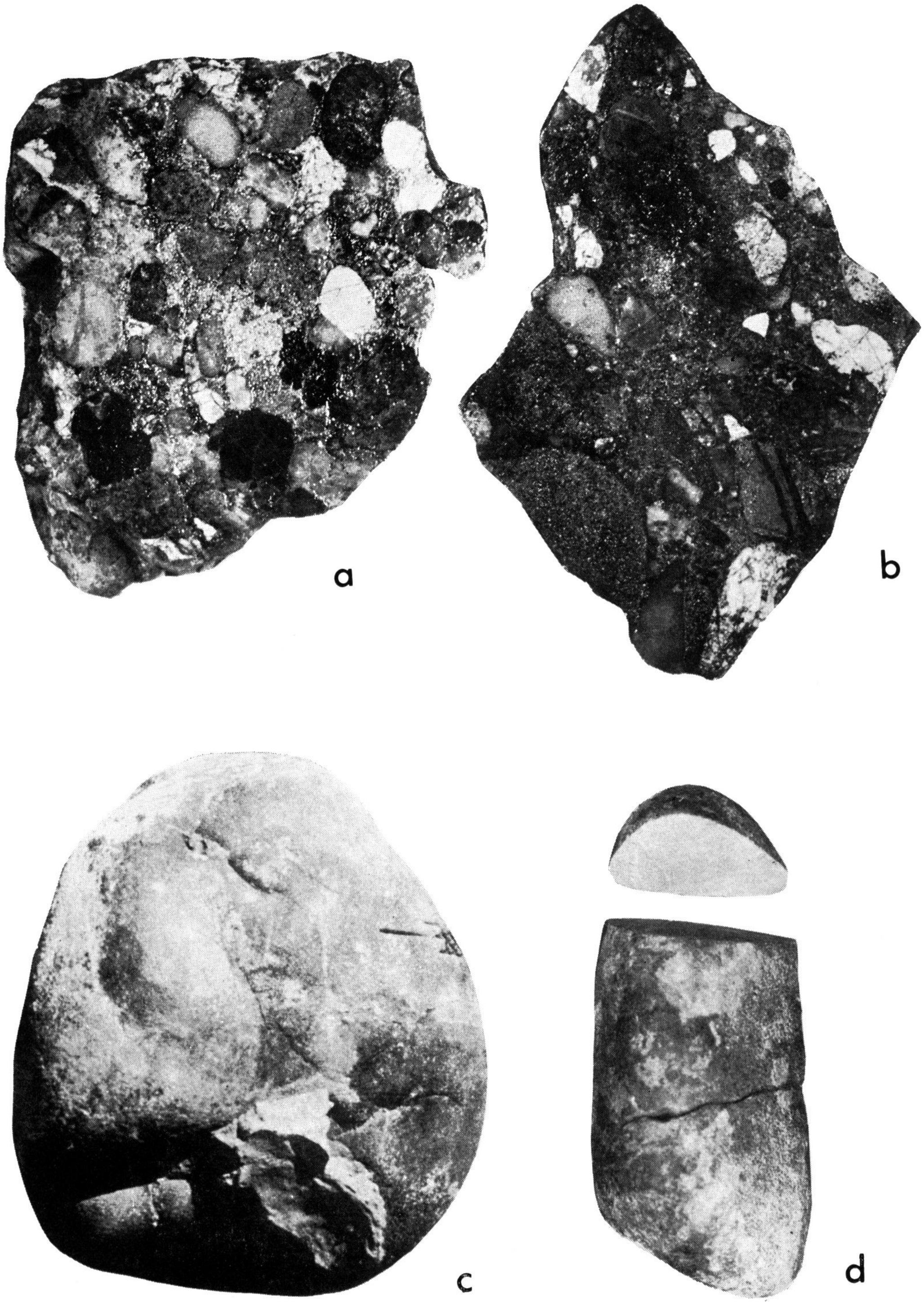
PLATE

Explanation of Plate 23

Occurrences of orthoquartzitic gravels in the Paleogene Muro group

Fig. a, b: Polymictic conglomerates containing orthoquartzitic gravels (a: Loc. C–2, b: Loc. C–4). Natural size

Fig. c, d: The biggest orthoquartzite gravel and the next biggest one. (c: Loc. C–5 Sample No. 436, d: Loc. C–5 Sample No. 437). $\times 1/2$



TOKUOKA: Orthoquartzitic Gravels in the Paleogene Muro Group, Southwest Japan

Explanation of Plate 24

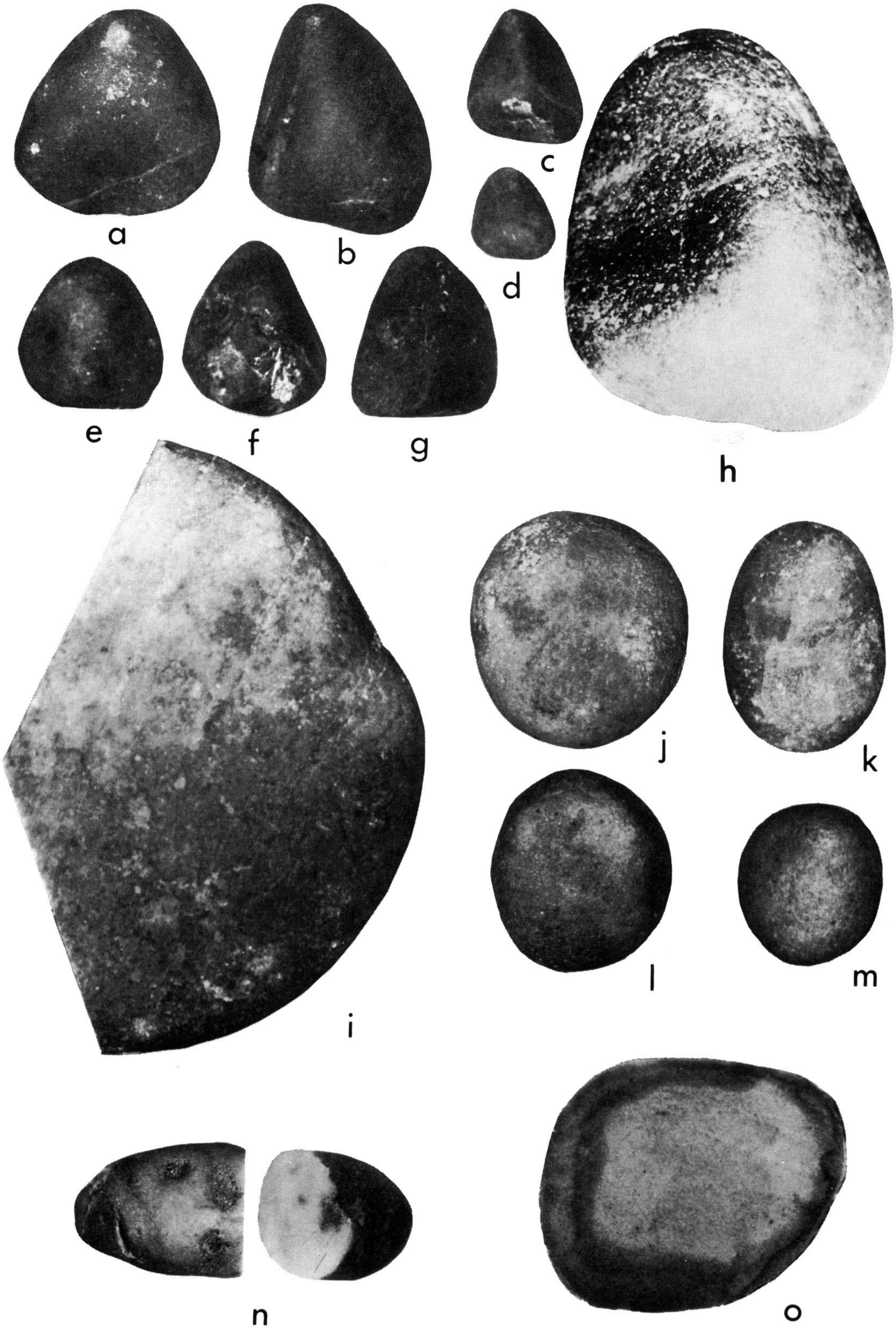
External features of orthoquartzitic gravels

Fig. a-h: Typical tetrahedroid gravels. Natural size.

Fig. i-m: Typical beach gravels (disk-shaped and very rounded). Natural size (i: Sample No. 110)

Fig. n: Pitted gravel. Natural size (Sample No. 30)

Fig. o: The gravel having limonite-stained crust. Natural size (Sample No. 108)



TOKUOKA: Orthoquartzitic Gravels in the Paleogene Muro Group, Southwest Japan

Explanation of Plate 25

Internal sedimentary features of orthoquartzite gravels

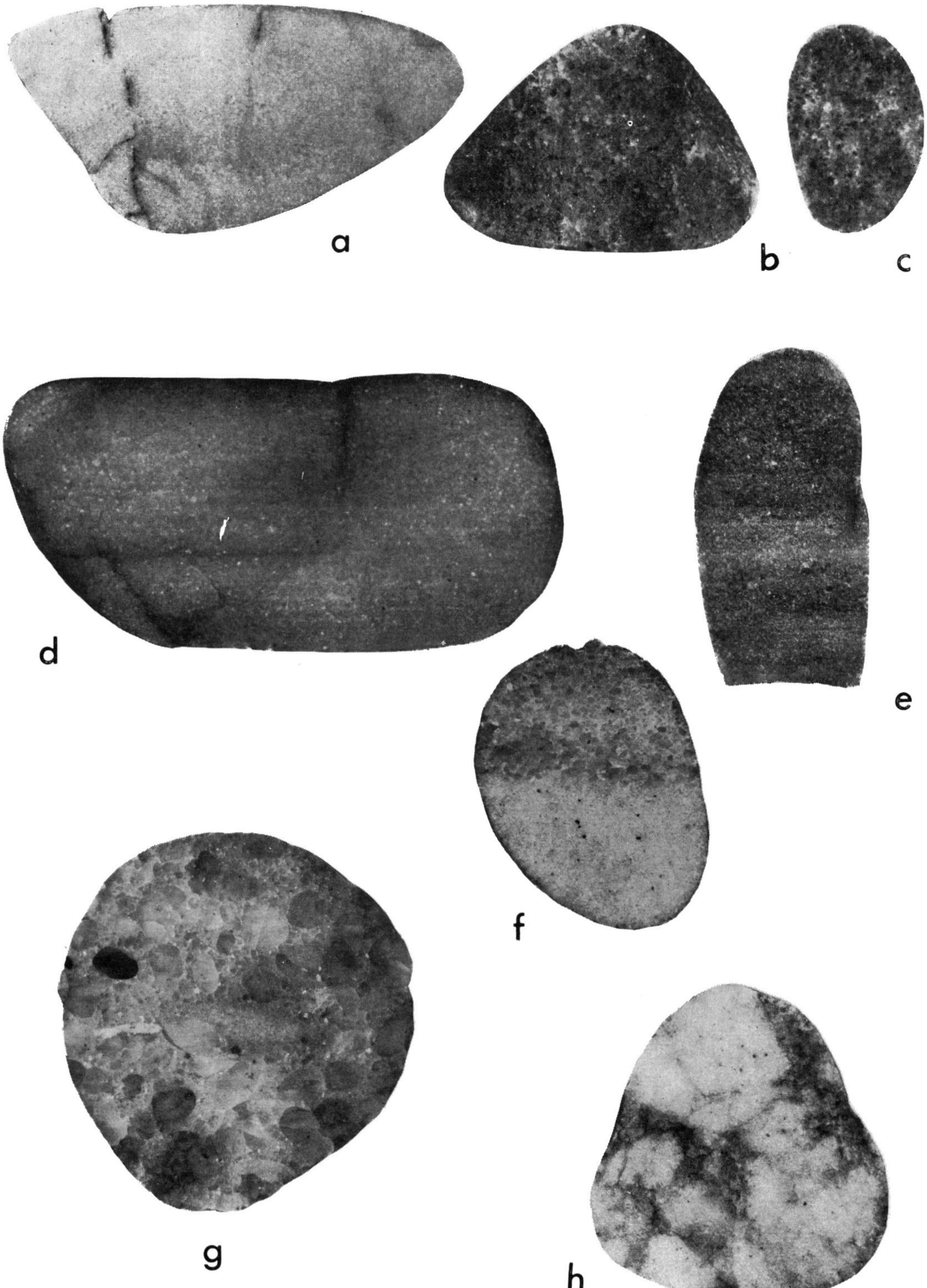
Fig. a-c : Massive orthoquartzites. Natural size (a: Sample No. 249, b: 172, c: 305)

Fig. d, e: Parallel laminated orthoquartzites. ×2 (d: Sample No. 48, e: 195)

Fig. f : Orthoquartzite composed of two parts of different grain size. ×2 (Sample No. 27)

Fig. g : Orthoquartzite made of well rounded granule quartz-grains. ×2 (Sample No. 379)

Fig. h : Orthoquartzite having mylonitic texture. Natural size (Sample No. 109)



TOKUOKA: Orthoquartzitic Gravels in the Paleogene
Muro Group, Southwest Japan

Explanation of Plate 26

Textural and compositional properties of orthoquartzite gravels under the microscope

Fig. a, b: Typical orthoquartzite (Type A–1). Each worn quartz grain is clearly shown by dust ring. Secondary overgrowth of quartz is very remarkable. Crystallographic continuity between worn grains and secondary overgrown parts is apparent. (a: ordinary light, b: crossed nicols, Sample No. 348)

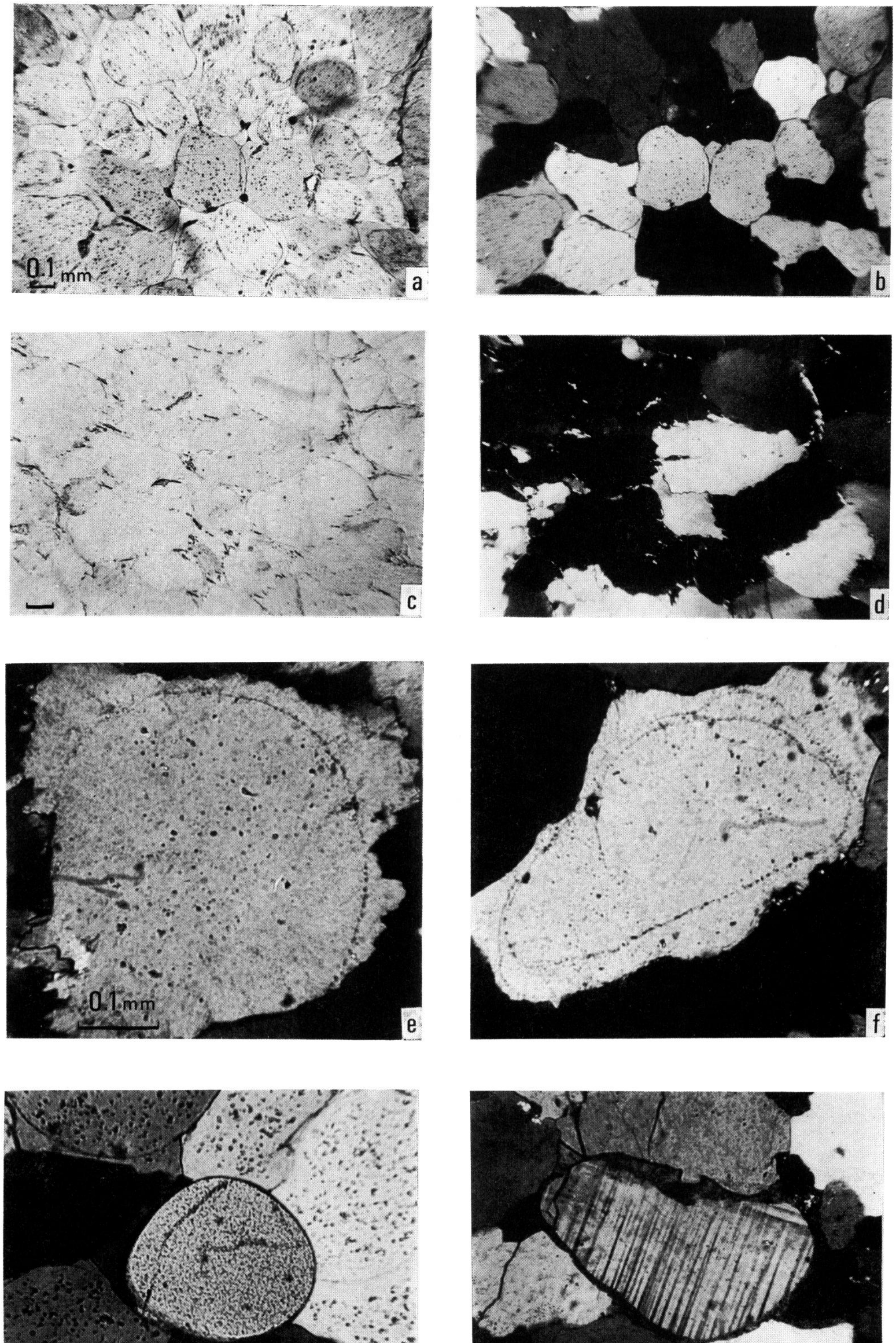
Fig. c, d: Schistose quartzite (Type B). Original grains were deformed and pressolved showing highly interlocking texture. Dust rings around original quartz grains are partly preserved. Chloritic minerals altered from original detrital matrices are visible around the deformed and rearranged quartz grains. The scale is 0.1 mm. (c: ordinary light, d: crossed nicols, Sample No. 151)

Fig. e: Partly but clearly preserved dust ring around quartz grain in schistose quartzite. Highly interlocking and sutured features are clearly shown. (crossed nicols, Sample No. 45)

Fig. f: Double dust rings around quartz grain suggesting two generations of secondary quartz. Scale is the same as fig. e. (crossed nicols, Sample No. 209)

Fig. g: Well rounded detrital tourmaline grain surrounded by overgrown quartz grains. The scale is 0.1mm. (crossed nicols, Sample No. 110)

Fig. h: Authigenic feldspar around the abraided K-feldspar grain. The scale is 0.1 mm. (crossed nicols, Sample No. 179)



TOKUOKA: Orthoquartzitic Gravels in the Paleogene Muro Group, Southwest Japan